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ON THE CHANGE IN STRENGTH CHARACTERISTICS OF LOESS SOIL OF THE ROAD BED

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ABSTRACT

Results of strength study of the road bed under the influence of multiple and short-term loads are dealt in this paper. The sequence of realization of laboratory and field studies, results of experimental data and conclusions are given.

KEYWORDS: Road Bed Short-Term Loads, Loess Soils, Strain, Compaction, Shear Stability, Working Layer, Angle of Internal Friction & Cohesion

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Original Article

1. INTRODUCTION

Currently, the traffic intensity on roads is rapidly increasing. This leads to an increase in load acting on the pavement and road bed. Besides, the pavement and road bed as the elements of environment are affected by climatic conditions.

When designing roads, the selected pavement design is tested for strength. Road paving is considered durable provided if is under the influence of short-term and repeated loads from moving vehicles, and if it maintains continuity and smoothness during its service life. Most of the irregularities on the coating are due to the strain in road bed soil under the influence of multiple transport loads.

2. SIGNIFICANCE OF THE SYSTEM

It is known that with an increase in the moisture content of loess soils, their mechanical properties sharply change. With this in mind, a design scheme (Figure 1) has been developed. The working layer is at some distance from the source of moistening; in this case, from the groundwater level. Moistening occurs due to the capillary rise of groundwater and the penetration of precipitation through road pavement and roadsides. In this case, it is necessary to take into account the changes in groundwater level over time. In this scheme, the repeated loads from vehicles are transmitted through the pavement to the working layer soil of the road bed.

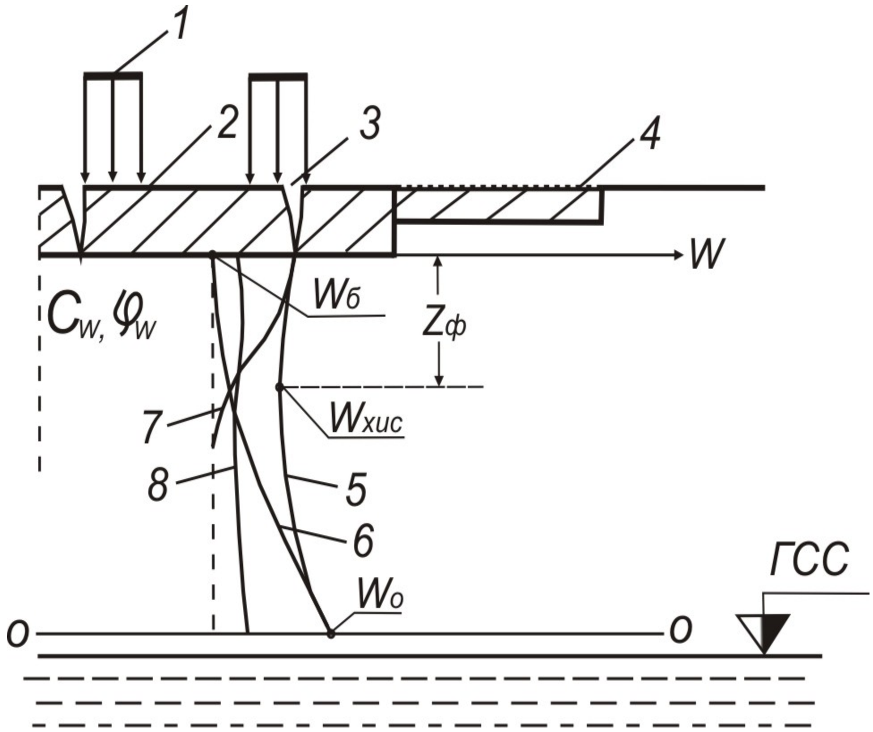

Figure 1: The Scheme to Determine the Strength Characteristics of Working Layer Soil of the Road Bed.

Wб-is the initial moisture content,%; *Wxuc*-is the calculated moisture content,%; *Wo* – is the moisture content at the yield strength,%; C_W is the cohesion force, *MPa*; φ_W - is the angle of internal friction, deg.; *Zф* – the active (working) layer, m.

1 – the load from car wheels; 2 – the pavement; 3 – the cracks in the coating; 4 – the roadside; 5 - the total moisture content; 6 – the capillary rise in moisture content; 7- the infiltration moisture content; 8 – the diffusion moisture content; *ГСС* – the groundwater level.

3. LITERARY SURVEY

An analysis of publications and regulatory documents on road construction shows that the consideration of multiple transport loads when calculating the shear in road bed loess soil is not sufficiently taken into account in the existing methods for calculating the road pavement; this can cause an accumulation of residual strain. In this regard, the problem of shear stability of loess soils in the bases of pavements seems relevant.

There are just a few studies of the shear stability of soils under the influence of multiple transport loads on the coating; some investigations by V. D. Kazarnovsky [1] for cohesive soils, by A. N. Pilipenko [2] for clay soils and by V. M. Smirnov [3] for sandy soils. However, such studies have not yet been conducted for loess soils.

Studies of shear stability of soils underlying road pavement under the influence of short-term and repeatedly applied loads show that the strength characteristics of soils cohesion *C* and the angle of internal friction φ depend on numerous factors; first of all, on the intensity and mode of action, stress state, soil condition in terms of moisture and density, type of soil, structural features. These dependencies can be expressed as follows:

$$C, \varphi = f(K_Y, N_P, W_P, I_P), \quad (1)$$

where K_Y –is the compression ratio; N_P - the amount of load applied; W_P – the estimated moisture content; I_P - the plasticity number.

4. PROPOSED METHODOLOGY AND DISCUSSIONS

To determine the strength characteristics of loess soils from the functions entering (1), laboratory and field studies were carried out on experimental sites. Based on the data of field study on experimental sites, the densities of loess soil of the road bed at the time of construction were compared with the density after 15 years of its operation. These studies show that the compression ratio is practically a stable index (with a confidence probability of 0.95) and it does not change over time.

Laboratory experiments were carried out in loess, dusty sandy loams, with a plasticity number PI = 5.35, moisture content at yield strength W_m = 29.1%; moisture content under rolling W_p= 23.8%; the maximum density at a standard compression of 1780 kg/m^3 and the optimum moisture content W_{on} = 17.5%. To determine the angle of internal friction and specific cohesion of soils, the samples were prepared in the following way. The naturally built soil of an undisturbed structure was pre-moistened to 17.5%. For a uniform distribution of moisture, the wetted area of soil was covered with a plastic film.

After excavation, it decomposed into a system of aggregates of undisturbed structure of various sizes. Soil compaction to a compression ratio K_Y = 0.96 on the ring of the GGP-30 shear device (Maslov-Lurie design), with a height of h = 3.5 cm and a diameter of d = 7.1 cm, was carried out on a hydraulic press with a short-term repeated action, at specific pressure - 0.7 MPa. The total aging time of the sample under load was 2 min. Before determining the strength characteristics of compacted aggregated soils, short-term and cyclic loads were applied to the sample.

Considering that the car wheel pressure on the pavement P = 0.6 MPa decreases (at road bed soil it reached P = 0.1 Mpa), this load is transferred to the sample in cycles. The order of application of the cyclic load is carried out as follows. A special element is installed on the lever of the device GGP-30 transmitting vertical pressure on soil; it allows us to convert a constant static load to a short-term cyclic one.

During the experiment, the duration of the vertical load on the sample was 0.1-0.3 sec, and the interval between load applications was 0.3-0.5 sec. The number of short-term load applications was recorded using an electric meter installed on the device. After every 1, 10, 10^2, 10^3, 10^4, 10^5, 10^6 loads strength characteristics on six compacted soil samples were determined. Experimental results are shown in Table 1.

Table 1: Strength Characteristics of Loess Sandy Loam depending on the Estimated Number of Load Applications (ΣNp)

Compression Ratio K_Y	Soil Moisture Content, Fraction W_T	Strength Characteristics of Soils: Angle of Internal Friction (deg.) / Cohesion (Mpa)				
		$\sum N_P=1$	$\sum N_P=10^3$	$\sum N_P=10^4$	$\sum N_P=10^5$	$\sum N_P=10^6$
0.94	0.55	31 / 0.031	29 / 0.030	28 / 0.029	26 / 0.027	25 / 0.027
	0.60	27 / 0.028	26 / 0.026	24 / 0.025	22 / 0.023	21 / 0.022
	0.65	24 / 0.024	23 / 0.023	22 / 0.022	20 / 0.020	19 / 0.19
	0.70	23 / 0.019	22 / 0.018	21 / 0.017	20 / 0.017	19 / 0.016

Experimental results show that with an increase in the number of load applications under equal conditions, i.e. at the same density and moisture content, the values of the angle of internal friction and specific cohesion decrease.

To confirm the results of laboratory tests in field conditions, the strength characteristics of the loess soil of the road bed were investigated. In experimental sites 300 m long, at embankment height 1.30 m, light sandy loam was compacted layer by layer in sections by 40 cm at the optimum moisture content with A-12 vibratory rollers to a compression ratio of 0.96.

The pavement was laid on top of the road bed, of total thickness of 45 cm. The site was divided into six sections, 50 m long. After each 1, 10^1, 10^2, 10^3, 10^4 passage of trucks, the pits were laid in the sections and on the upper part of the roadbed; $C_{гр}$ and the angle of internal friction $\varphi_{гр}$ using a single-plane rotation cut, moisture content (by gravimetric method), soil density were determined [4].

The strength characteristics determined on a single-plane rotation cut device were compared for control with the values of the angle of internal friction and cohesion obtained in laboratory conditions on the Maslov-Lurie device during testing of soil monoliths taken from the construction site.

An analysis of the results obtained in the field is confirmed by laboratory studies; they show that at almost the same density and moisture, with an increase in the number of load applications, the cohesion and the angle of internal friction of soil decrease.

5. EXPERIMENTAL RESULTS

Results of field and laboratory experiments can be explained as follows. According to the opinions of the scientists studying soil issues V. D. Kazarnovsky [1], A. K. Larionov [6], N. N. Maslov [7], E. M. Sergeyev [8] and others, there are macro-and micropores in the naturally formed soil and they are retained when the soil is crushed into aggregates. When compressing soils to the desired degree of compaction, these pores are retained in the form of large and small pores between the aggregates and inside the aggregates, affecting their physical and mechanical properties.

Under the influence of short-term and repeated loads, stresses and vibrations on compacted soil, partial destruction of compacted aggregates into smaller ones occurs. The destruction and change in the aggregates and soil particles arrangement occur. When determining the total specific cohesion of soil samples C_W, consisting of additionally crushed and deformed aggregates, according to Prof. Maslov, the cohesion of water-colloidal soils and the reversible nature of Σ_W at moisture content W remains constant, because the structural bonds C_C of the aggregates and particles, formed under natural conditions for a long time, are destroyed. As a result, the total specific cohesion of soils $C_{гр}$ decreases.

It is known [7, 9,10] that the surface roughness of particles and aggregates determine the state of the angle of internal friction of soils. After short-term and repeated loads influence on soil sample and as a result of crushing large aggregates into smaller ones, the surface roughness of aggregates and particles decreases, and, the angle of internal friction decreases as well.

6. CONCLUSIONS AND RECOMMENDATIONS

In the practice of pavement design, the use of data from Table 1 is not always convenient, since the values of cohesion C and the angle of internal friction φ are given for discrete values, i.e. $W_p = 0.55 \div 0.70$; $K_y = 0.90 \div 1.00$; $N_p = 1 \div 10^6$.

Therefore, we attempted to propose mathematical expressions for determining C, φ, for various values of N_p, W_p, and K_y.

The methods to obtain the expressions for determining the cohesion force and the angle of internal friction are as follows:

- According to Table 1 dependence of $C_{гр}$ on N_p at K_y=0, 94; W_p=0, 55 can be written in the following form:

$$C_N=0,032-0,001lgN_p;\ \text{MPa} \quad (2)$$

However, in this expression, the unit of measurement does not correspond to the unit of measurements of cohesion, therefore, we transform (2) to the following form:

$$C_N=C_0(1,032-0,032lgN_p);\ \text{MPa} \quad (3)$$

where: C_0 is the soil cohesion at N_p=1; K_y=0,94; W_p=0,55, C_0=0,031 MPa.

- With an increase in W_p, the value of soil cohesion C_W decreases. According to Table 1 at N_p=1 and K_y = 0.94, the dependence of C_W on moisture content (i.e., the change in cohesion within the moisture range of 0.55 ÷ 0.70 W_m) can be written as:

$$C_W=0,073W_p-0,04. \quad (4)$$

However, in expression (4) the unit of measurement is not defined, therefore, we will artificially modify it to the following form:

$$C_W=\Delta C_W(2,35W_p-1,29),\ \text{MPa}; \quad (5)$$

where: ΔC_W - is the soil cohesion at K_y=0,94; N_p=1; W_p=0,55. ΔC_W=0,031MPa.

- With increasing compression ratio, the value of cohesion increases as well. According to Table 1 at W_p=0, 55 and N_p=1, the increase in cohesion depending on K_y (i.e., the change in cohesion force C_K depending on K_y within 0.94 ÷ 1.00) can be written as:

$$C_K=0,483\ K_y - 0,45 \quad (6)$$

Transform formula (6) into (7) so that the unit of measurement corresponds to the unit of measurement of cohesion:

$$C_K=\Delta C_K(15,58\ Ky - 14,64),\ \text{MPa}; \quad (7)$$

where: ΔC_K is the soil cohesion at K_y=0,94; N_p=1; W_p=0,55. ΔC_K=0,031MPa.

In general case, dependence C on K_y, N_p and W_p has the following form:

$$C= C_N - C_W + C_K \quad (8)$$

Substituting (3), (5) and (7) into (8) we get the following expression:

$$C=C_0(1,032-0,032lgN_P)-\Delta C_W(2,35W_P-1,29)+\Delta CK_y(15,59K_y-14,51),\ \text{MPa} \quad (9)$$

The angle of internal friction was determined for loess sandy loam in this sequence:

$$\varphi=\varphi_0(1-0,032lgN_P)-\Delta\varphi_W(1,72W_P-0,95),\ ^o \quad (10)$$

where: φ_0 – is the coefficient that accounts for the increment (decrement) of the angle of internal friction depending on the number of load applications N_P; $\Delta\varphi_W$ is the coefficient that accounts for the increment (decrement) of the angle of internal friction depending on W_P; $\varphi_0 = \Delta\varphi_W = 31°$.

The expressions given above are recommended to use in pavement calculation for shear resistance.

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